

NASA DC-8 Airborne Scanning Lidar Sensor Development*

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ABSTRACT

The NASA DC-8 aircraft is used to support a variety of *in-situ* and remote sensors for conducting environmental measurements over global regions. As part of the atmospheric effects of aviation program (AEAP) the DC-8 is scheduled to conduct atmospheric aerosol and gas chemistry and radiation measurements of subsonic aircraft contrails and cirrus clouds. A scanning lidar system is being developed for installation on the DC-8 to support and extend the domain of the AEAP measurements. Design and objectives of the DC-8 scanning lidar are presented.

1.0 INTRODUCTION

The atmospheric effects of subsonic and supersonic aircraft fleets need better definition before substantial budgets are approved for development of advanced aircraft and their operational scenarios. As part of the atmospheric effects of aviation project (AEAP), NASA has formulated an extensive field program termed the subsonic aircraft: contrail and cloud effects special study (SUCCESS) to be conducted during April and May 1996 with flights of multiple aircraft over the clouds and radiation testbed (CART) site operated by the Department of Energy. One of the aircraft will be the NASA DC-8 with installation of state-of-the-art atmospheric chemistry sensors. SRI International (SRI) and Raytheon Aerospace Company are developing a DC-8 scanning lidar that can be operated with pointing angles of vertical upward to forward to vertical downward so that angular sectors can be observed as illustrated in Figure 1.

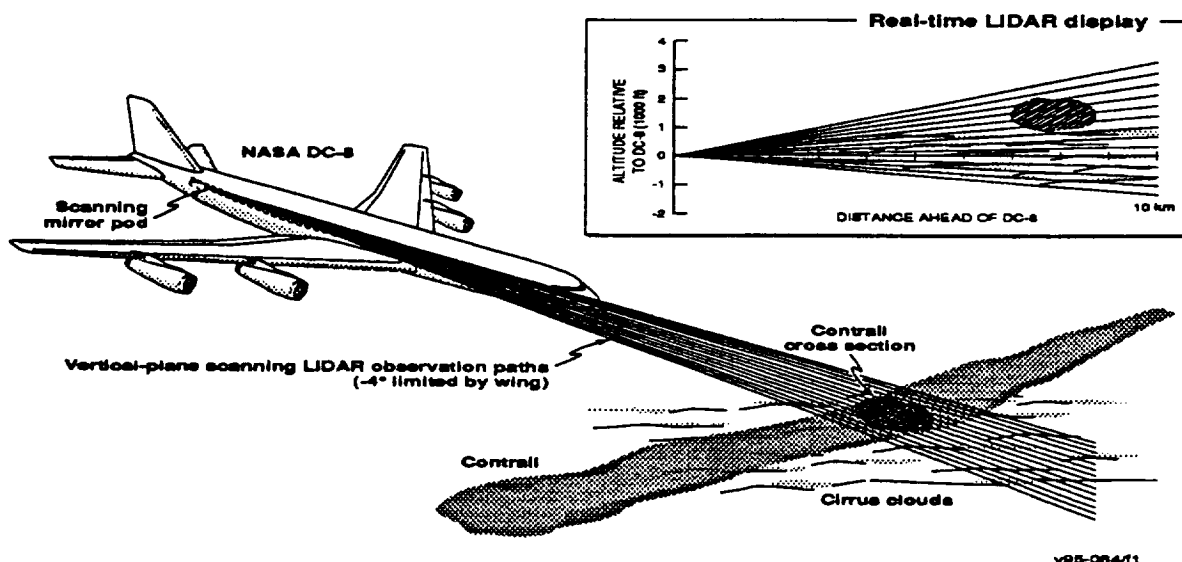


Figure 1 DC-8 Scanning Lidar Illustration

*To be presented at the Second International Airborne Remote Sensing Conference and Exhibition, San Francisco, California, 24-27 June 1996.

The objectives of the DC-8 scanning lidar are listed below:

- Map contrail/cloud vertical distributions ahead of the DC-8
- Provide DC-8 guidance into enhanced scattering layers
- Document DC-8 flight path intersection of contrail and cloud geometries
 - *In-situ* measurement positions relative to cloud/contrail shapes
 - Extension of *in-situ* measurements into the vertical (integrated contrail/cloud properties)
- Analyze contrail/cloud radiative properties with LIRAD (combined lidar and radiometry) technique
- Evaluate mean particle sizes of aircraft emissions from two-wavelength lidar observations
- Study contrail/cloud interactions, diffusion, and mass decay/growth.

Design details of the lidar are presented in the following sections of this paper.

2.0 LIDAR SYSTEM

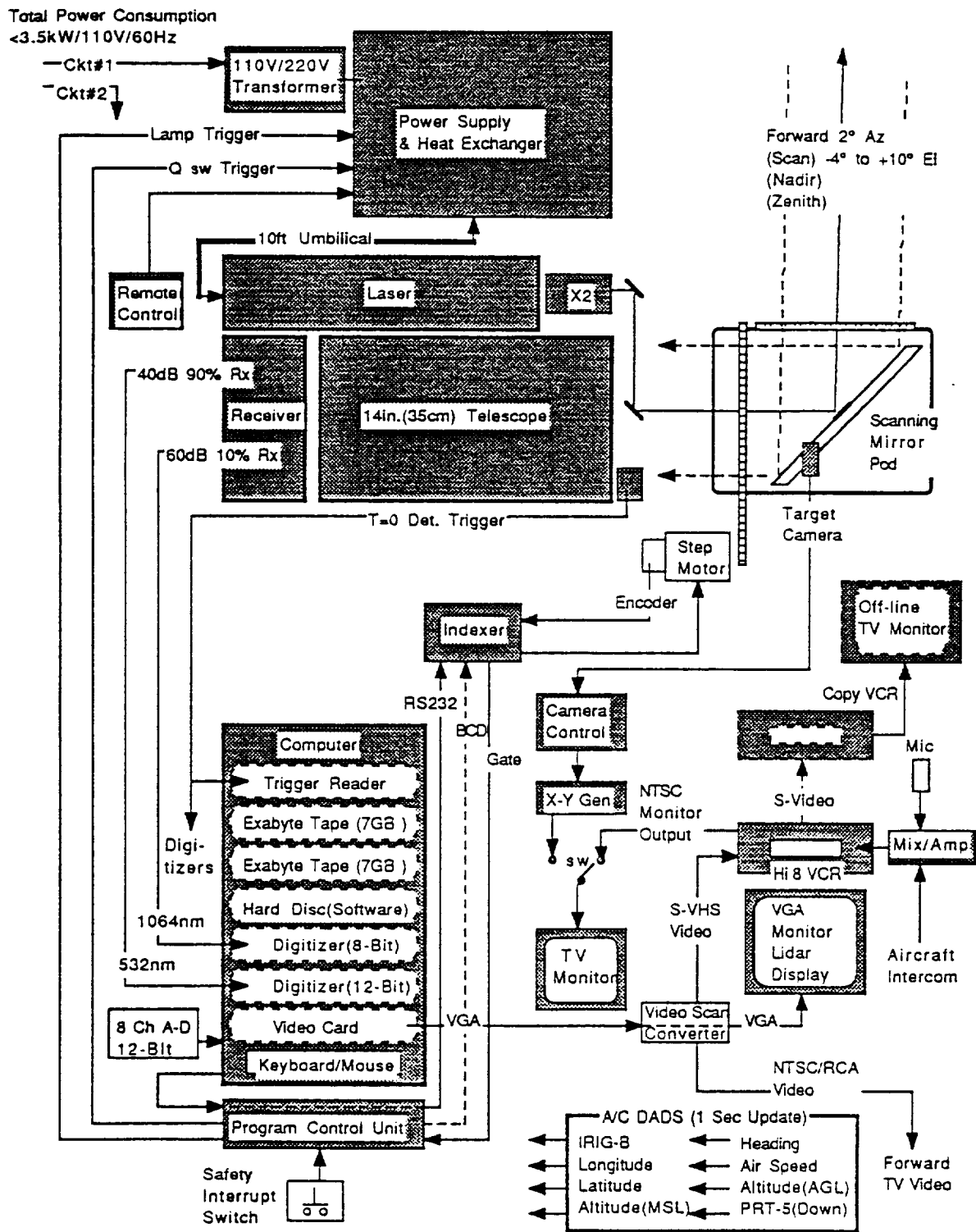
The DC-8 scanning lidar system comprises four major modules: laser transmitter, telescope receiver, data acquisition system, and scanning mirror pod. The first three modules are integrated into a standard DC-8 aircraft equipment rack. The telescope and laser are mounted on top of the rack with the receiver field of view and laser beam coaxial and directed through an aircraft side window port into the scanning mirror pod attached to the outside DC-8 fuselage.

2.1 TRANSMITTER

A block diagram showing lidar components is illustrated in Figure 2. The laser is a Spectra Physics model DCR-11 ND:YAG with a second harmonic frequency doubler. The laser runs at 10 Hz with approximately 130 mJ at both of the two wavelengths (1064 nm and 532 nm). The laser power supply and heat exchanger are contained in a separate package mounted directly to the seat rails. The flash lamp and Q-switch trigger pulses are supplied from a custom lidar program control unit. The pulses are synchronized to 60 Hz line frequency to avoid possible ground loop interferences.

2.2 RECEIVER

The lidar telescope has a 35 cm aperture with a Cassegrain configuration. Backscattered light from atmospheric aerosols is collected by the telescope and divided into two channels with a dichoric beam splitter. After passing through narrow band interference filters to reduce background light levels, the light from each channel is focused onto a solid state detector. On Channel 1 the 1064 nm detector (3 mm diameter) is enhanced for this wavelength and used in combination with a 60 dB logarithmic amplifier to obtain a large operating dynamic range. Data collected on this channel is primarily for short-range observation while flying directly through cirrus clouds and aircraft contrails. Channel 2 can be used for either the 1064 nm or 532 nm wavelength depending on receiver optical elements. The percentage of energy in each channel can be controlled by the beam splitter. The detector on Channel 2 is smaller in size (0.8 mm) and has more gain and radiant responsivity. This high sensitivity channel uses a 40 dB logarithmic amplifier and is used for long-range observation of sub-visible clouds. In addition to the data from the two logarithmic channels, linear data from each channel can be digitized and recorded. For



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Figure 2. SRI DC-8 Lidar Configuration (component block diagram)

special experiments a polarizer can be added to the 1064 nm channel to differentiate between crystal structure of cirrus clouds and aircraft contrails.

2.3 DATA SYSTEM

The lidar data acquisition system is based on an IBM PC. Up to four channels of data can be processed, using Gage Applied Sciences digitizers, and recorded on Exabyte tape. The two linear channels use 12-bit 30 MHz digitizers and the two logarithmic amplifier channels use 8-bit 50 MHz digitizers. A low-speed 8 channel 12-bit A-D card is available for processing signals from associated meteorological sensors such as a narrow-beam radiometer. The DC-8 aircraft flight parameters and related environmental data available on a NASA supplied data network is input to the lidar data system for recording and presentation on the lidar displays.

A program control unit controls the stepping motor drive of the scanning mirror, and synchronizes it with the laser firing and data acquisition. The motor position is read by the lidar computer and added to the recorded data array. The lidar data are processed and displayed as color modulated pictorial displays in real time, on a flat panel VGA color monitor, and also a monitor at the DC-8 Mission Manager station. The video signal passes through a scan converter and is recorded on a HI-8 VCR (>400 line resolution) so that it may be analyzed on standard television receivers.

2.4 LIDAR SCANNER

A design study was conducted at NASA Ames using a preliminary scanning mirror concept and optical specifications provided by SRI. The design study identified the structural, aerodynamic, and system requirements to balance the performance needs of the lidar, while ensuring the scanner pod to be airworthy. Because *in-situ* sampling ports needed installation in the front sections of the DC-8, the lidar scanner was designed for installation in the rear section of the aircraft and makes use of one of the DC-8's side-viewing window ports.

A pressurized scanner pod was developed that consists of a large flat 45° diagonal mirror and an optical window mounted on a bearing assembly that is installed outside the aircraft in a cylindrical configuration as illustrated in Figure 3. Pressurization at the pod surfaces eliminates the need for a window at the DC-8 fuselage surface and reduces the total number of optical surfaces interacting with laser pulses. The pod is motor-driven and computer-controlled for positioning or scanning. It can be used in either a forward, upward, or downward viewing configuration. The pod can be locked into any desired position with a pair of opposing cam clamps. Adjustable mechanical stops limit scanning of the pod from intersecting the wing area of the aircraft. An indexed template marked in degrees indicates the pointing position of the scanner. A fairing was designed, as illustrated in Figure 4, with the assistance of NASA aerodynamicists to provide a smooth air flow around the scanner pod. The fairing is mounted to the side of the aircraft behind the scanner using two unused window ports to provide the attachment mounting support.

The scanner provides a 35 cm aperture for the lidar telescope receiver and will accommodate other SRI lidar systems. The front surface diagonal mirror is designed to be 1/8 wave flat. This helps maintain the astronomical quality of the telescope and allow focusing of backscattered light onto millimeter-sized diameter optical detectors. In the center of the large diagonal mirror is an additional laser transmitter mirror that allows the lidar to be operated in a coaxial configuration. The high energy transmitter mirror is 2 in. in diameter and can be changed to accommodate other wavelength lidar systems. The pressurized optical window of the pod (following the 45° mirror) is made of BK-7 glass, 17 in. in diameter, and 1-1/4 in. thick. It has a high energy anti-reflection coating on both surfaces to aid transmission and minimize

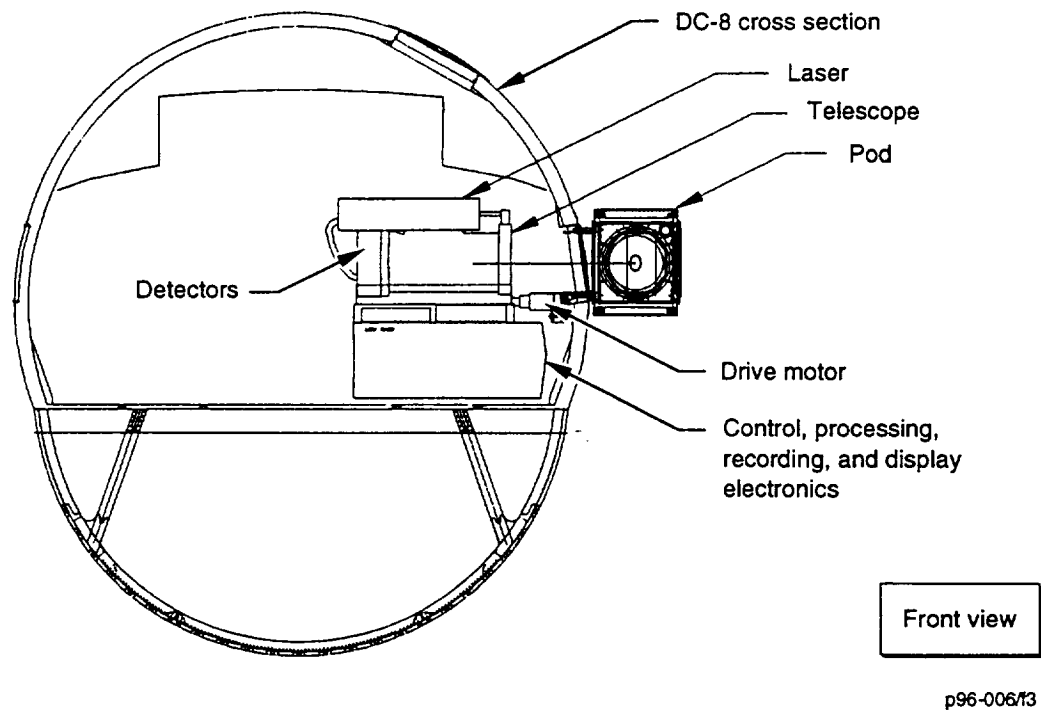


Figure 3. SRI Scanning Lidar Installation NASA Ames DC-8

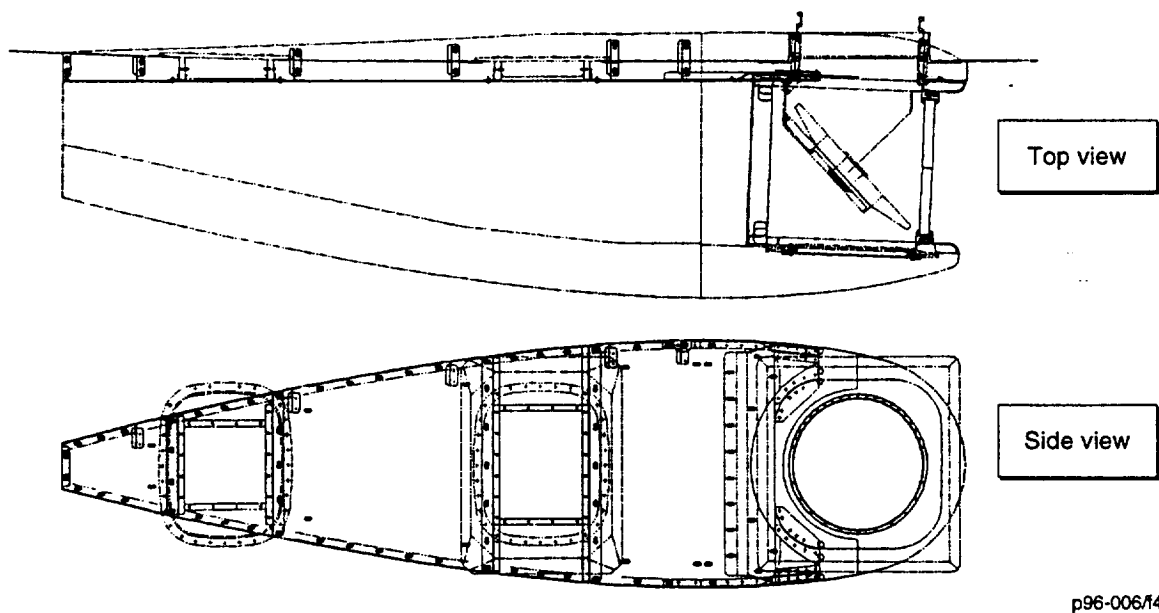


Figure 4. DC-8 Lidar Scanning Mirror Pod and Aerodynamic Fairing

energy reflection into the telescope. During landing and takeoff the scanner pod window is pointed in the aft facing direction into the fairing for protection and for receiver calibration against a low light level background.

The complete pod system and aerodynamic fairing have been analyzed for aircraft pressurization and aerodynamic loads and airworthy tests are in process.

3.0 CONCLUSIONS

An airborne scanning lidar has been developed for installation on the NASA DC-8 to support atmospheric chemistry and radiation measurements. At the time of this writing, the lidar was being integrated on the DC-8 in preparation for a study of aircraft contrails and cirrus clouds related to atmospheric effects of aviation. Data collection is scheduled during April/May 1996 and, therefore, lidar data examples should be available for presentation at the conference.

4.0 ACKNOWLEDGMENTS

The design, construction, and application of the scanning lidar system to atmospheric measurements is sponsored under NASA Ames Research Center Cooperative Agreement NCC 2-885.